



U.S. Department
of Transportation
**Federal Aviation
Administration**

Advisory Circular

Subject: AUTOMATIC PILOT SYSTEMS
INSTALLATION IN PART 23
AIRPLANES

Date: 3/4/91
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Change:

1. PURPOSE. This advisory circular (AC) sets forth acceptable means, but not the only means, of showing compliance with the Federal Aviation Regulations (FAR), applicable to automatic pilot system installation in part 23 airplanes. This material is neither mandatory nor regulatory in nature and does not constitute a regulation.

2. RELATED REGULATIONS AND DOCUMENTS.

a. Regulations. These acceptable means of compliance refer to certain provisions of part 23 of the FAR. They may be used in showing compliance with the corresponding provisions of the former Civil Air Regulations (CAR) in the case of airplanes to which the CAR regulations are applicable. For convenience, the part 3 section reference is shown in parenthesis, following the part 23 section reference:

- § 23.143 (3.106) - General, Controllability and Maneuverability
- § 23.253 - High speed characteristics
- § 23.395 (3.231) - Control system loads
- § 23.397 (3.212) - Limit control forces and torques
- § 23.689 (3.345) - Cable systems
- § 23.777 (3.384) - Cockpit controls
- § 23.779 (3.384) - Motion and effect of cockpit controls
- § 23.1301 (3.651 and 3.652) - Function and installation
- § 23.1309 - Equipment, systems, and installations
- § 23.1321 (3.661 and 3.662) - Arrangement and visibility
- § 23.1322 - Warning, caution, and advisory lights
- § 23.1329 (3.667) - Automatic pilot system
- § 23.1351 (3.681) - General, Electrical Systems and Equipment
- § 23.1381 (3.396 and 3.697) - Instrument lights
- § 23.1431 (3.721) - Electronic equipment
- § 23.1555 (3.762, 3.763, and 3.765) - Control markings
- § 23.1581 (3.77) - General, Airplane Flight Manual and Approved Manual Material
- § 23.1583 (3.778) - Operating limitations
- § 23.1585 (3.779) - Operating procedures

b. Advisory Circulars. The advisory circulars listed below can be obtained from the U. S. Department of Transportation, Utilization and Storage Section, M-443.2, Washington, D.C. 20590:

AC 21-16C Radio Technical Commission for
 Aeronautics Document DO-160C

AC 23.1309-1 Equipment, Systems, and Installations
 in Part 23 Airplanes

c. Technical Standard Orders. The Technical Standard Order listed below can be obtained from the Federal Aviation Administration, Aircraft Certification Service, Aircraft Engineering Division, Technical Analysis Branch (AIR-120), 800 Independence Ave., SW, Washington D.C. 20591:

TSO-C9 Automatic Pilot

d. Industry Documents. The RTCA documents listed below are available from the Radio Technical Commission for Aeronautics (RTCA), One McPherson Square, Suite 500, 1425 K Street, NW, Washington, D.C. 20005:

RTCA/DO-160C Environmental Conditions and Test
 Procedures for Airborne Equipment

RTCA/DO-178A Software Consideration in Airborne
 Systems and Equipment Certification

3. BACKGROUND. AC 23.1329-1, Automatic Pilot Systems Approval, which set forth an acceptable means for showing compliance with the automatic pilot installation requirements, was issued December 23, 1965. Although AC 23.1329-1 was inadvertently canceled in 1977, criteria essentially equivalent to that contained therein continued to be used to show compliance with the applicable autopilot installation requirements. The airworthiness regulations prescribe the requirements for automatic pilot installation approval. The following criteria have been applied and found reasonable and acceptable in previous type certification programs for complying with specific sections related to these approvals.

a. Compliance with the regulations necessitated the conversion of the force exerted by one pilot to overpower an engaged automatic pilot into measurable terms when an autopilot quick disconnect and/or interrupt switch was not provided. The values in the table under § 23.143 are maximums. There may be circumstances where a maximum force less than 75 pounds is required for safety. For example, if a pilot is trying to overpower a nose up malfunction during climb and reduce power at the same time, a maximum safe force may be less than 75 pounds. Consequently, these forces, as measured at the pilot's controls were equated to the following temporary and prolonged forces:

(1) The maximum temporary force to overpower the automatic pilot has not been allowed to exceed 30 pounds in roll (force applied at the rim of the wheel), 50 pounds in pitch, and 150 pounds in yaw. These forces are applicable only to initially overpowering the automatic pilot system.

(2) The maximum prolonged force to overpower the automatic pilot must not exceed 5 pounds in roll, 10 pounds in pitch, and 20 pounds in yaw.

b. A reasonable period of time has been established for pilot recognition between the time a malfunction is induced into the automatic pilot system and the beginning of pilot corrective action following hands off or unrestrained operation. The following time delays have been acceptable:

(1) A 3-second delay following pilot recognition of an automatic pilot system malfunction, through a deviation of the airplane from the intended flight path, abnormal control movements, or by means of a reliable failure warning system, in the climb, cruise, and descent flight regimes.

(2) A 1-second delay following pilot recognition of an automatic pilot system malfunction, through a deviation of the airplane from the intended flight path, abnormal control movements, or by means of a reliable warning system, in maneuvering and approach flight regimes.

4. ACCEPTABLE MEANS OF COMPLIANCE. The following procedure, in accordance with the forces and times of paragraph 3 above is acceptable as a means of showing that an automatic pilot system installation is in compliance with the airworthiness rules:

a. Cockpit Controls. Evaluation of cockpit controls should include the following:

(1) Location of automatic pilot system controls are such that their operation is readily accessible to the pilot, or both pilots, if a minimum of two pilots are required.

(2) Annunciators conform to the proper color as specified in § 23.1322.

(3) A determination that the controls are readable and discernible under bright sunlight and night lighting conditions (§ 23.1381).

(4) Quick disconnect and/or interrupt switches for the automatic pilot system are located on the side of the control wheel opposite the throttle(s) and are red in color. A disconnect switch stops all movement of the autopilot system. An interrupt switch momentarily interrupts all movement of the autopilot system.

(5) A determination that any automatic disconnects of the autopilot are adequately annunciated by an aural warning. If warning lights are utilized to supplement the aural warning, they should meet the requirements of § 23.1322. Use of a visual warning as the sole means of annunciating automatic disconnects is not considered acceptable.

(6) Motion and effect of autopilot cockpit controls must conform with the requirements of §§ 23.1329(c) and 23.779.

b. Malfunction Evaluations.

(1) Malfunction evaluation flights should be conducted with the airplane loaded at the most critical weight or most critical center of gravity/weight combination. Maximum untrimmed fuel imbalance should be considered during the evaluation. If auto-throttles are installed, they should be operating. Autopilot servo torque should be set to the upper tolerance limit. The simulated malfunctions should be induced at various airspeeds and altitudes throughout the airplane's airspeed and altitude envelopes including the maximum operating altitude for turbocharged or high altitude airplanes or within 10 percent of the service ceiling for normally aspirated airplanes, and when the airplane is stabilized in the normal operational attitudes being evaluated. Vertical gyro mechanical failures should not be considered. The simulated failure and subsequent corrective actions are not acceptable if they result in any of the following:

(i) Loads that exceed the substantiated structural design limit loads;

(ii) Acceleration outside the 0 to 2g envelope, the positive "g" limitation may be increased up to the positive design limit maneuvering load factor if it has been previously determined analytically that neither the simulated failure nor subsequent corrective action would result in loads beyond the design limit loads of the airplane;

(iii) Speeds in excess of V_{NE} or for airplanes with an established V_{NO}/M_{NO} , a speed midway between V_{NO}/M_{NO} and the lesser of V_D/M_D , or the speed demonstrated under § 23.253.

(iv) Deviations from the flight path including bank angle in excess of 60° or pitch attitude in excess of $\pm 30^\circ$ deviation from the attitude at which the malfunction was introduced; or

(v) A hazardous dynamic condition.

(2) Normal Flight Malfunctions. The airplane's performance should be evaluated when the effect caused by the most critical single failure condition that can be expected to occur to the system and can be detected by the pilot is induced into the

automatic pilot system. Hidden or latent failures, in combination with detectable failures, should be considered when determining the most critical failure condition. Normal flight includes climb, cruise, and descent flight regimes, with the airplane properly trimmed in all axes. Airplane configurations (combinations of gear and flaps), speeds, and attitudes should be evaluated for unsafe conditions of the more critical of the following simulated malfunctions:

(i) A simulated malfunction about any axis equivalent to the cumulative effect of any failure or combination of hidden failures, including manual-electric or automatic trim if installed.

(ii) The combined signals about all affected axes, if multiple axis failures can result from the malfunction of any single component. Since amendment 3-2 to part 3 of the CAR effective August 12, 1957, the requirements are that an autopilot system must be designed so that a single malfunction will not produce a hardover signal in more than one control axis (reference §§ 3.667(e) and 23.1329(e)).

NOTE: A 3-second delay following pilot recognition of an autopilot system malfunction, as indicated in paragraph 3(b)(1), should be applied for normal flight malfunction evaluations.

(3) Maneuvering and Approach Malfunction. Maneuvering flight tests should include turns with the malfunction induced at the maximum bank angles for normal operation, up to and including the automatic pilot authority limits. Airplane configurations (combinations of gear and flaps), airspeeds, and altitudes should be evaluated to determine if unsafe conditions exist. Simulated malfunctions described for normal flight malfunctions, as indicated in paragraphs 4b(2)(i) and (ii) are applicable for introduction during maneuvering flight malfunction evaluation. The resultant accelerations, loads, and speeds should be within limits described for normal flight malfunctions. Malfunctions introduced during coupled approaches should not place the airplane in a hazardous attitude or an attitude that would prevent the pilot from conducting a missed approach or safe landing. Altitude losses resulting from the simulated malfunctions are to be measured accurately and presented in the limitations section of the Airplane Flight Manual (AFM) or approved manual material. A 1-second delay following pilot recognition of an automatic pilot system malfunction, through a deviation of the airplane from the intended flight path, abnormal control movements, or by means of a reliable warning system should be applied in maneuvering and approach flight regimes.

NOTE: Accurate measurement of altitude loss, due to an automatic pilot malfunction during an instrument landing approach, is essential. This altitude loss, during a critical phase of flight, provides the basis for establishing the minimum approach altitude during automatic pilot coupled approaches. It is to be determined by measuring from the altitude at which the malfunction is induced

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to the lowest altitude observed during the recovery maneuver unless instrumentation is available to measure the vertical deviation from the intended glide path to the lowest point in the recovery maneuver. Appendix 1 contains a method of measurement for approach altitude loss. Altitude losses due to malfunctions in other flight regimes, though less critical, may be determined by measuring the deviation from the flight path in a manner similar to that used for the glide slope.

(4) Alternate Means of Compliance for Autopilots Incorporating Electronic Monitors/Limiting Devices. Listed below are alternate means of compliance. These alternate means cite considerations for evaluating monitors and/or limiting devices when the functioning of such devices is necessary to prevent the airplane from exceeding the malfunction limits identified in paragraph 4b(1) of this circular.

(i) Alternate Means No. 1.

(A) Monitor/Limited Inhibited. With the monitor/limited inhibited, automatic pilot malfunction flight testing may not cause:

- (1) Roll to exceed 80°.
- (2) Pitch to exceed +45°, -35°.
- (3) Accelerations outside the 0g to 2.5g

envelope.

(4) Airspeed exceeding V_{NE} or for an airplane with an established V_{NO}/M_{NO} , a speed not greater than a speed midway between V_{NO}/M_{NO} and the lesser of V_D/M_D or the speed demonstrated under § 23.253.

(B) Reliability and Prerequisite Criteria.

(1) A fault analysis should show that the probability of a monitor failure, combined with an automatic pilot malfunction, is less than 1×10^{-5} per flight hour.

(2) Preengagement check of the monitor is mandatory. No credit is allowed for a pilot-activated preengagement check unless there is a lockout device or system.

(ii) Alternate Means No. 2.

(A) Monitor/Limited Inhibited. With the monitor/limited inhibited, automatic pilot malfunction flight testing may not cause:

- (1) Roll to exceed 80° .
- (2) Pitch to exceed $+45^\circ$, -35° .
- (3) Accelerations outside the $-0.2g$ to $2.5g$ envelope.
- (4) Airspeed exceeding V_{NE} or for an airplane with an established V_{MO}/M_{MO} , a speed not greater than a speed midway between V_{MO}/M_{MO} and the lesser of V_D/M_D or the speed demonstrated under § 23.253.

(B) Reliability and Prerequisite Criteria.

- (1) An acceptable fault analysis showing that the probability of a combined monitor failure and an automatic pilot malfunction is less than 1×10^{-7} per flight hour. In addition, the probability of failure of a lockout device to inhibit autopilot engagement as identified in paragraph (B)(3) below, is less than 1×10^{-5} per flight hour.
- (2) Preengagement check of the monitor is mandatory with either a manual or automatic activation means.
- (3) Automatic pilot engagement inhibited until preengagement check is successfully completed.

(iii) Alternate Means No. 3.

(A) Flight tests with monitors inhibited are not required.

(B) Reliability and Prerequisite Criteria.

- (1) An acceptable fault analysis showing that the probability of a combined monitor failure and automatic pilot malfunction is less than 10^{-9} per flight hour. In addition, the probability of failure of a lockout device/system to inhibit autopilot engagement as identified in paragraph (3) below, is less than 10^{-7} per flight hour.
- (2) Preengagement check of the monitor system is mandatory with either a manual or automatic activation means.
- (3) Automatic pilot engagement inhibited until the preengagement check is successfully completed.
- (4) Automatic pilot authority not greater than necessary to satisfactorily control the airplane.

c. Recovery of Flight Control. Evaluate the ability to recover flight control from the engaged automatic pilot system by manual use of a quick disconnect and/or by physically overpowering the system.

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d. Performance Flights. Performance evaluation tests should be conducted with the airplane loaded to its most adverse center of gravity and weight condition. Automatic pilot performance with the servo torque values at the lowest production torque tolerance limit should be used to demonstrate safe controllability and stability. Flight tests are necessary to assure the automatic pilot system performs its intended function, including all modes of operation presented for approval (reference § 23.1301).

e. Single-Engine Approach. For multiengine airplanes, an engine failure during a normal instrument landing system (ILS) approach should not cause a lateral deviation of the airplane from the flight path at a rate greater than 3° per second or produce hazardous attitudes. This rate should be measured and averaged over a 5-second period. If approval is sought for ILS approaches initiated with one engine inoperative, the automatic pilot should be capable of conducting the approach.

f. Airplane Flight Manual (AFM) Information. The following information should be placed in the AFM, the Pilot's Operating Handbook (POH), or presented to the pilot in the form of placards:

(1) In the Operating Limitations Section, the airspeed limitations, maximum altitude for operation if different from the maximum certificated altitude of the airplane, category of ILS approaches for which approval is granted, minimum approach height, and any other applicable limitations.

(2) In the Operating Procedures Section, the normal operating information, including navigation and glide slope intercept recommendations. For those automatic pilot systems which incorporate monitors and/or limiter devices, the preengagement procedures and the means of indicating that the preengagement has been successfully completed.

(3) In the Emergency Operation Procedures Section:

(i) A statement of the altitude loss in the cruise, climb, and descent configurations, and maneuvering flight conditions, due to possible malfunctioning of the autopilot system.

(ii) A statement of the altitude loss due to malfunctions while in the approach configuration. If engine inoperative approach is approved, the altitude loss should be included.

(iii) Any other procedure related to emergency procedures associated with the autopilot and/or associated systems.



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APPENDIX 1. ALTITUDE LOSS

1. Malfunction inducement point.
2. Malfunction recognition by pilot.
3. Initiation of manual recovery action by pilot.
4. Altitude loss with no instrumentation.
5. Altitude loss with instrumentation.

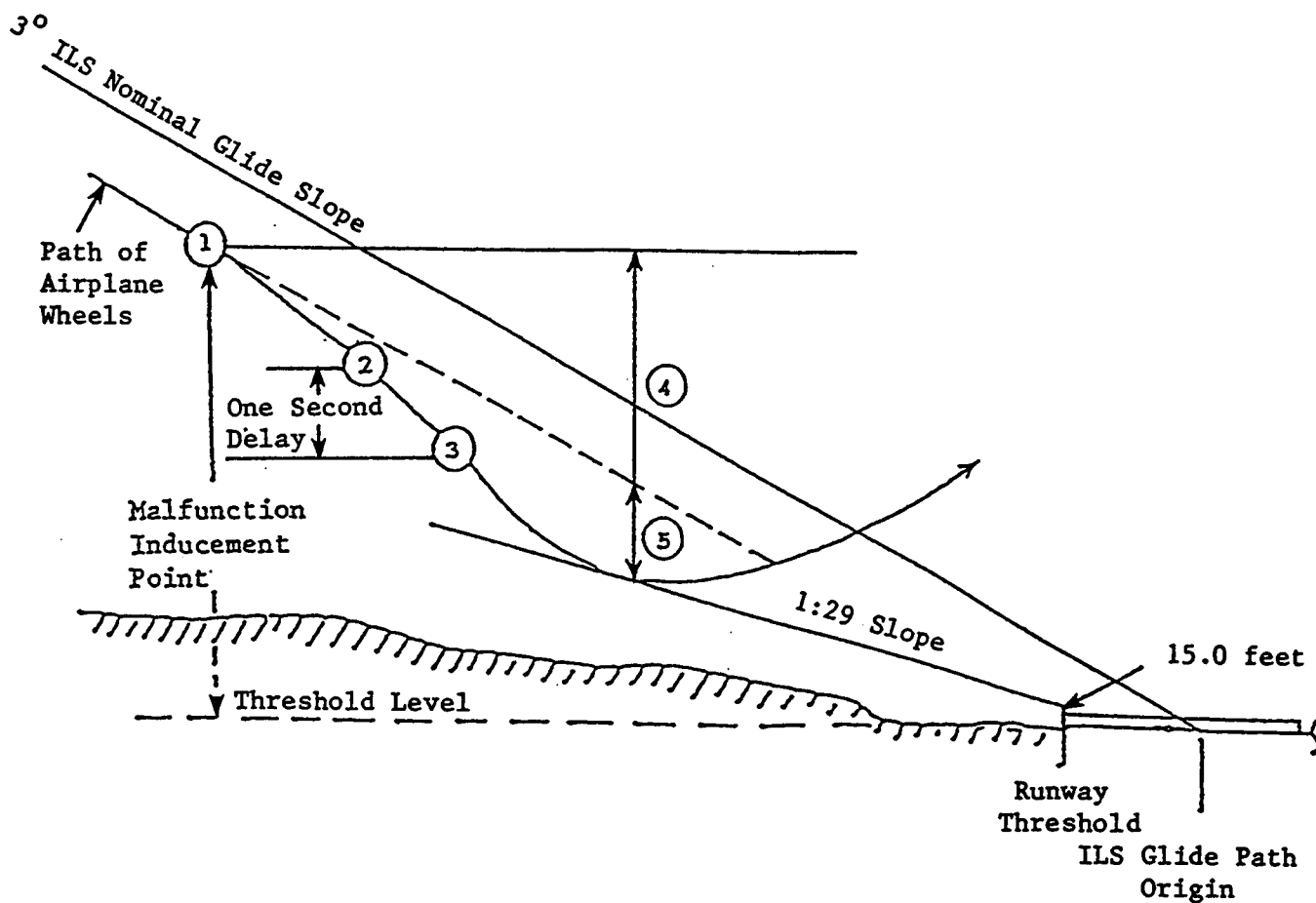


Figure 1 - ACCEPTABLE METHOD FOR DETERMINING
ALTITUDE LOSS IN APPROACH

Malfunction Evaluations. The airplane should be established on the ILS glide path and localizer in the configuration(s) with the approach speed(s) specified by the applicant for approach. Simulated automatic flight control system malfunctions should be induced at critical points along the ILS, taking into consideration all design variations and their limits in automatic flight control system sensitivity and authority. The malfunctions should be induced in each axis. While the pilot may know the purpose of the flight, they should not be informed when a malfunction is to be or has been applied except through a deviation of the airplane from the intended flight path, abnormal control movements, or by means of a reliable failure warning system. After a failure, recovery should be initiated 1 second after the pilot recognizes the failure.

a. A 3 degree glide path should be used for these tests in order to determine the malfunction effects to be expected in service.

b. For use during a coupled ILS approach, the automatic control system should not fail in such a way that it causes the airplane wheels to descend below a limit line lying below the glide slope, sloping upward at 29:1 from a point fifteen feet above the runway threshold. With the airplane established on the glide slope in approach configuration, at approach speed, the most critical malfunction is induced at a test altitude referenced to the runway threshold. Measure the altitude loss between the test altitude and the lowest point of the manual recovery unless instrumentation is available to measure the vertical deviation from the intended glide path to the lowest point in the recovery maneuver. The altitude loss and the known distance to the threshold from the lowest recovery altitude are compared to the limit line. The lowest test altitude from which a malfunction and manual recovery can be completed without the airplane wheels descending below the limit line is considered the minimum height for use of the automatic flight control system.

c. Recovery from all malfunctions should be demonstrated either by overpowering or by manual use of an emergency quick disconnect device after the appropriate delay. The pilot should be able to return the airplane to its normal flight altitude under full manual control without exceeding the defined limits.

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